MODIFICATION OF THE MAZE PROCEDURE FOR ATRIAL FLUTTER AND ATRIAL FIBRILLATION

II. Surgical technique of the maze III procedure

The operative technique of the maze III procedure for the treatment of patients with medically refractory atrial flutter and atrial fibrillation is described in a sequential fashion. The accompanying diagrams of the procedure are illustrated from the view of the operating surgeon. (J THORAC CARDIOVASC SURG 1995;110:485-95)

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As described in the preceding article, follow-up evaluation of the first 32 patients to undergo the original maze I procedure revealed that 6 months after the operation there was frequently a blunted sinus node response to maximum exercise and an unsatisfactory incidence of left atrial dysfunction.[1] As a result, the original surgical technique was modified in an effort to overcome these two long-term sequelae. These modifications evolved into the maze III procedure, which is now considered to be the surgical technique of choice for the treatment of medically refractory atrial flutter and atrial fibrillation. It is the purpose of this paper to describe the surgical technique of the maze III procedure.

Surgical technique

Myocardial preservation technique. A variety of myocardial preservation techniques have been used and the choice remains that of the surgeon. If crystalloid cardioplegia is used, so that the aortic crossclamp time is critical, we prefer to perform the right atrial incisions in the beating, nonworking heart before applying the aortic crossclamp. The left atrial incisions would then be performed during crystalloid cardioplegic arrest, followed by closure of the right atrial incisions after release of the aortic crossclamp.

It is our current practice to perform the right atrial incisions *after* arresting the heart with blood cardioplegic solution. Our preference is to use aspartate-glutamate–enriched blood cardioplegic solution delivered alternately in the antegrade and retrograde fashion throughout all phases of the procedure. We prefer warm induction to attain complete electromechanical arrest, followed immediately by the infusion of enriched cold blood cardioplegic solution until the myocardial temperature reaches approximately 10° C. The initial right atrial incisions are then performed, followed by the left atrial incisions (described later). While the final left atrial incisions are being closed, we alternate antegrade and retrograde infusions of enriched warm blood cardioplegic solution until the myocardial temperature reaches approximately 34° C, by which time closure of the left atriotomies is usually complete and the aortic crossclamp can be removed.

Incision and cannulation technique. A median sternotomy is performed and the pericardium is opened longitudinally. After systemic heparinization, the aorta is cannulated and a right-angled venous return cannula is inserted through a purse-string suture in the superior vena cava (SVC) approximately 2 cm above the SVC–right atrial junction. A separate right-angled venous return cannula is then inserted through a purse-string suture in the lowest portion of the right atrium near its junction with the inferior vena cava (IVC). The IVC is usually mobilized thoroughly from its pericardial

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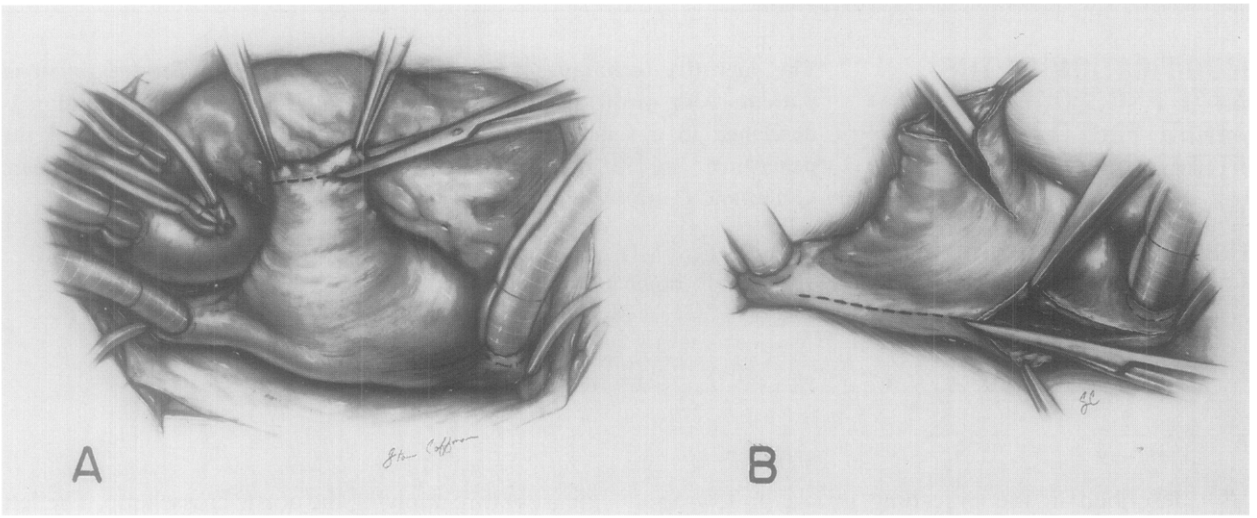

Fig. 1. A, The right atrial appendage is excised. At least 2 cm of visible atrial muscle should be preserved between the superior end of the excised appendage *(dashed line)* and the orifice of the SVC. **B,** A lateral incision, parallel to the right AV groove, is placed from the base of the excised atrial appendage toward the IVC, with 5 to 6 cm of right atrial free wall left between the lower end of this incision and the IVC cannula. A posterior longitudinal incision is then placed from well into the SVC *(dashed line)* to well into the IVC. (From Cox JL. The Maze III Procedure for Treatment of Atrial Fibrillation. In: Sabiston DC, ed. Atlas of Cardiothoracic Surgery. Philadelphia: WB Saunders, 1994:XIV-78. Modified and published with permission.)

investments before this suture is placed. In addition, although this cannulation site is positioned as low in the right atrium as possible, it is situated more *anteriorly* on the atrium than the IVC cannulation site for heart transplantation.

A Y-shaped cardioplegia infusion–aortic vent cannula is inserted into the ascending aorta. Umbilical tapes are passed around the SVC and IVC. Previously, a pulmonary artery vent was used in these patients, and one is shown in this series of drawings. More recently, we have been placing a left ventricular vent via the right superior pulmonary vein as soon as cardiopulmonary bypass is initiated. During placement of the left-sided incisions, the end of this vent is removed from the mitral valve orifice and positioned into the left inferior pulmonary vein orifice, a maneuver that improves the operative exposure substantially. Once the left-sided incisions have been completed, the tip of the vent is again passed across the mitral valve into the left ventricle, where it remains until the patient is ready to be weaned from cardiopulmonary bypass.

Preliminary dissection of extracardiac tissues. As in the maze I and maze II procedures, optimal surgical exposure is attained by extensive dissection of the extracardiac tissues before any incisions are made in the atrium. This preliminary dissection is unchanged from that previously described for the maze I procedure.[2] It involves extensive mobilization of the SVC and IVC, the interatrial groove, and the plane between the right pulmonary artery and the posterosuperior left atrium, as well as mobilization of the left atrium off the posterior pericardium between the right and left pulmonary veins.

Placement of the right atrial incisions. Cardiopulmonary bypass is instituted and the umbilical tapes are secured around the SVC and IVC, the latter being placed as low as possible to provide enough room for a later right atriotomy to extend well into the IVC. The aorta is crossclamped and the heart is arrested with antegrade enriched warm blood cardioplegic solution, as described earlier, while the systemic temperature is simultaneously reduced to 28° C.

The right atrial appendage is excised, with at least 2 cm of visible atrial tissue left between the incision and the anterior SVC (Fig. 1, *A*). The superior and inferior edges of the resultant atriotomy are grasped with clamps so that the atriotomy appears to be a straight slit in the atrium. A perpendicular incision is placed from the middle of this slit laterally down the free wall of the right atrium for approximately 2 cm. A posterior longi-

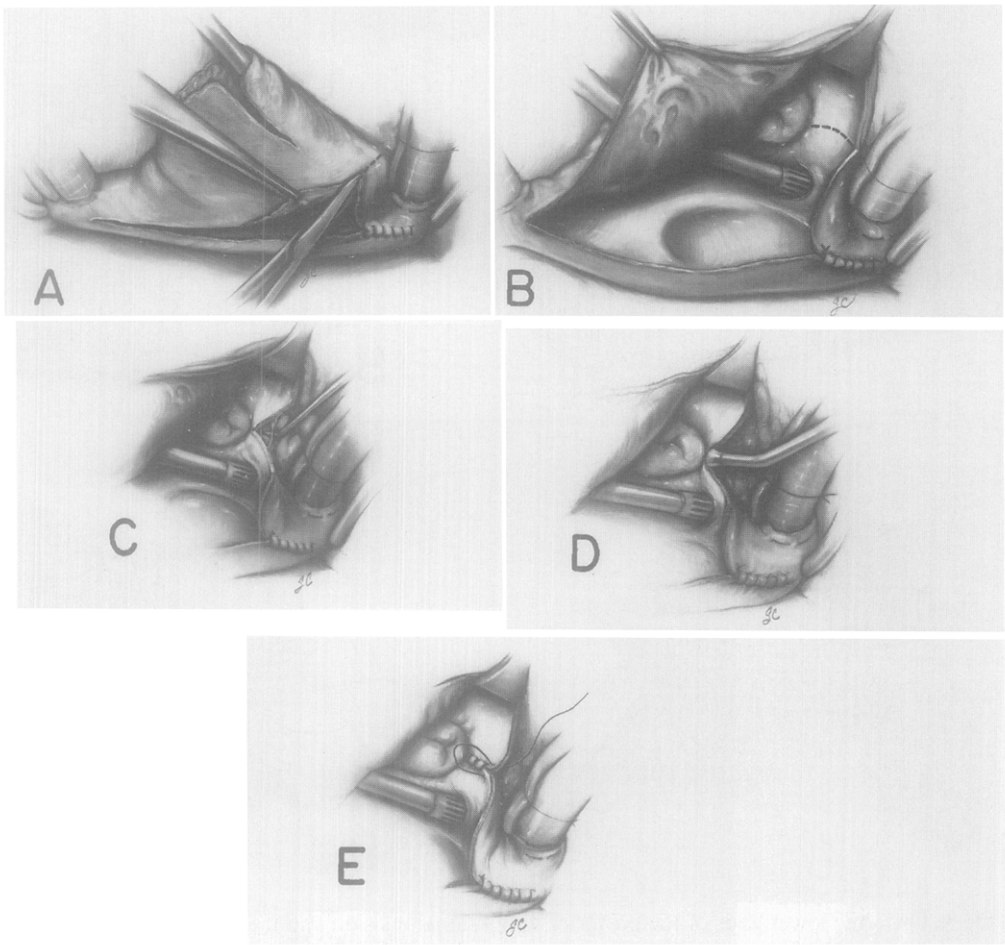

Fig. 2. A, The lower portion of the posterior longitudinal incision is closed immediately to prevent inadvertent tearing and extension of the incision into the IVC during later retraction. The incision is usually closed up to the level of the top of the IVC cannula. A T incision is then placed from this point across the lower right atrial free wall approximately 1 cm above the IVC cannula. The T incision is extended to the top of the right AV groove. The remainder of the incision, which will extend to the tricuspid valve anulus, must be made from inside the right atrium (*dashed line,* **B**). **B,** The right atrial free wall is retracted anteriorly and superiorly. The *dashed line* shows the planned extension of the T incision to the tricuspid anulus. This will continue to be a transmural atriotomy, but underlying this portion of the incision is the fat pad of the right AV groove that harbors the right coronary artery. **C,** It is essential that all atrial myocardial fibers traversing this portion of the T incision be divided with either a knife or a nerve hook. **D,** A cryolesion is placed at the tricuspid end of the T incision to be certain that no remaining fibers traverse the incision at the level of the tricuspid valve anulus. **E,** The tricuspid end of the T incision is closed up to the level of the top of the AV groove. The remainder of the incision is left unclosed to attain better surgical exposure during the remainder of the procedure. (From Cox JL. The Maze III Procedure for Treatment of Atrial Fibrillation. In: Sabiston DC, ed. Atlas of Cardiothoracic Surgery. Philadelphia: WB Saunders, 1994:XIV-78. Modified and published with permission.)

tudinal right atriotomy is then placed from above the orifice of the SVC to below the orifice of the IVC (Fig. 1, *B*). This atriotomy should be placed far enough posteriorly to avoid injury of the sinoatrial (SA) node. A longitudinal line of demarcation is usually visible between the thin free wall of the right atrium (bluish) and the thicker posterior wall of the right atrium (whiter). This incision can be placed safely either precisely on or slightly posterior to this line of demarcation. The IVC end of this posterior longitudinal atriotomy should be closed immediately to prevent tearing

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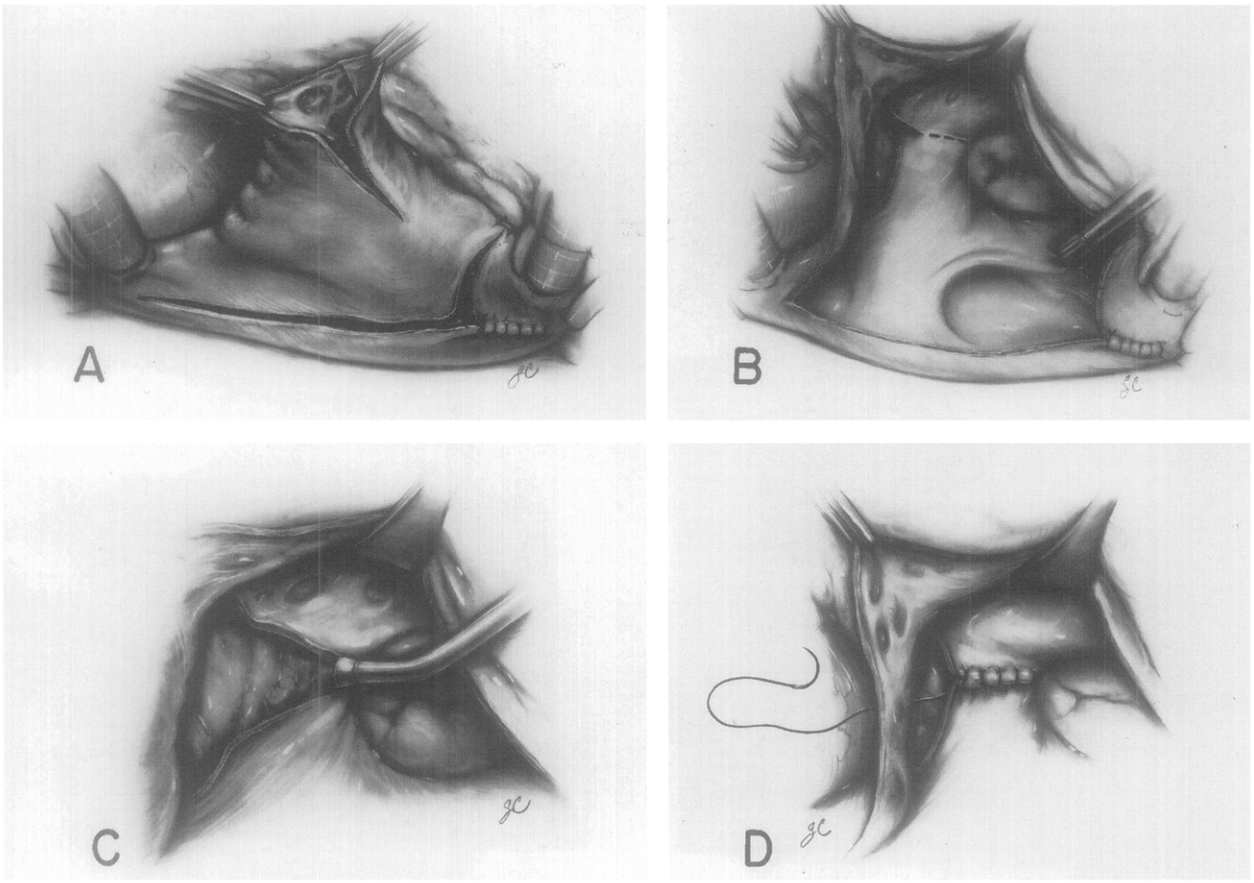

Fig. 3. A, Once the lower ends of the posterior longitudinal incision and the T incision have been closed, the anterior right atrial counterincision is performed, beginning at the anteromedial border of the excised right atrial appendage (*dashed line,* **A**). This incision will extend to the anteromedial tricuspid valve anulus. Once it is started, it is easier to complete from inside the right atrium. **B,** The right atrial free wall is retracted anteriorly and superiorly to expose the anteromedial portion of the tricuspid valve anulus and the upper portion of the counterincision that has been started from outside the right atrium. The *dashed line* in **B** shows the planned extension of this counterincision to the tricuspid valve anulus. **C,** The counterincision is transmural, but care must be taken in dividing the final myocardial fibers because the right AV groove fat pad lies immediately beneath the incision. This is the portion of the right AV groove that corresponds to the anterior septal space. In this case, the incision is approximately 2 to 3 cm anterior to the AV node–His bundle complex. The right coronary artery has usually not joined the right AV groove at this point, although anatomic variations exist. A 3 mm cryolesion is also placed at the tricuspid end of this incision to ensure its completion. This is the final right atrial incision. **D,** The entire counterincision is closed to the base of the excised atrial appendage. (From Cox JL. The Maze III Procedure for Treatment of Atrial Fibrillation. In: Sabiston DC, ed. Atlas of Cardiothoracic Surgery. Philadelphia: WB Saunders, 1994:XIV-78. Modified and published with permission.)

and extension of the incision down the IVC during later retraction. We usually close it to about the level of the top of the IVC cannula.

A perpendicular, or T, incision is placed from the posterior longitudinal atriotomy across the lower portion of the right atrial free wall approximately 1 cm above the IVC cannula (Fig. 2, *A*). This T incision is carried anteriorly to the level of the atrioventricular (AV) groove. The resultant flap of right atrial free wall is then retracted superiorly and anteriorly so that the right atrial endocardium between the end of the T incision and the tricuspid valve can be seen from inside the right atrium (Fig. 2, *B*). The T incision is then continued down to the level of the tricuspid valve anulus (*dashed line* in Fig. 2, *B*). Because the T incision must be transmural,

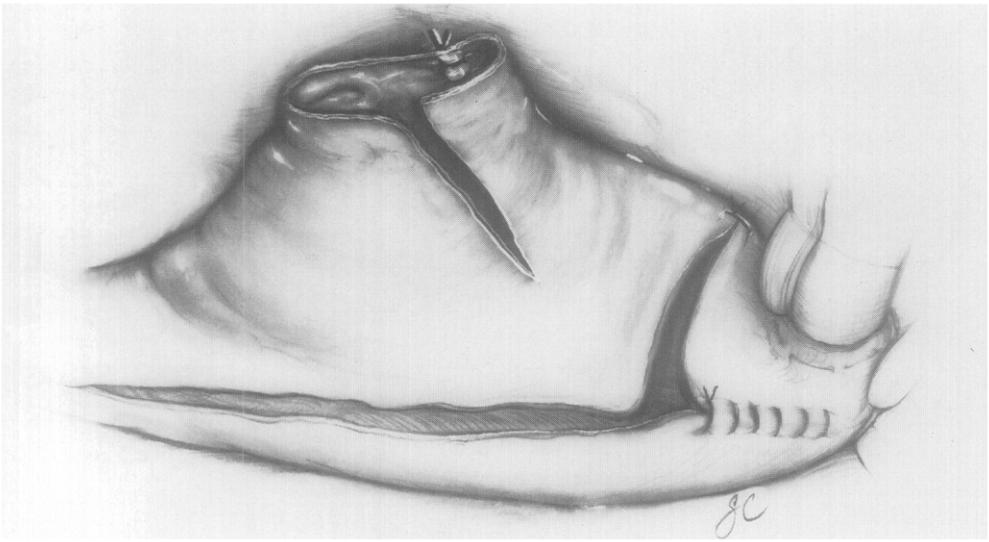

Fig. 4. Once the anteromedial counterincision has been closed, the remaining right atrial incisions are left unclosed until the left atrial operation has been completed. (From Cox JL. The Maze III Procedure for Treatment of Atrial Fibrillation. In: Sabiston DC, ed. Atlas of Cardiothoracic Surgery. Philadelphia: WB Saunders, 1994:XIV-78. Published with permission.)

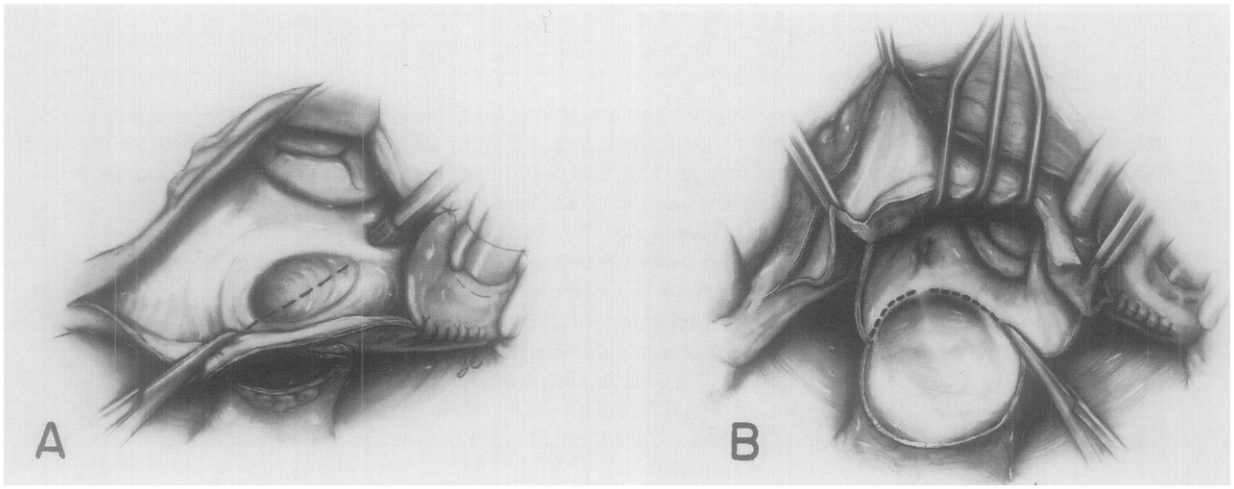

Fig. 5. A, A standard left atriotomy is performed in the interatrial groove, its lower end being extended around the lower lip of the right inferior pulmonary vein orifice. The atrial septum is then divided, beginning 2 to 3 cm below the orifice of the SVC, traversing the anterior limbus of the fossa ovalis, and then traversing the fossa ovalis itself *(dashed line)*. This septal incision should be slanted in the general direction of the os of the coronary sinus, but it is absolutely essential to terminate it at the bottom of the thin portion of the fossa ovalis. **B,** The atrial septum is retracted for optimal exposure of the left atrium, mitral valve, left pulmonary veins, and orifice of the left atrial appendage. The standard left atriotomy is extended *inferiorly* across the posterior left atrial free wall between the mitral valve and the orifices of the inferior pulmonary veins. Likewise, the *superior* portion of the standard left atriotomy is extended around the lip of the left superior pulmonary vein orifice. Before the two ends of this pulmonary vein isolation incision are joined, the left atrial appendage is excised. (From Cox JL. The Maze III Procedure for Treatment of Atrial Fibrillation. In: Sabiston DC, ed. Atlas of Cardiothoracic Surgery. Philadelphia: WB Saunders, 1994:XIV-78. Modified and published with permission.)

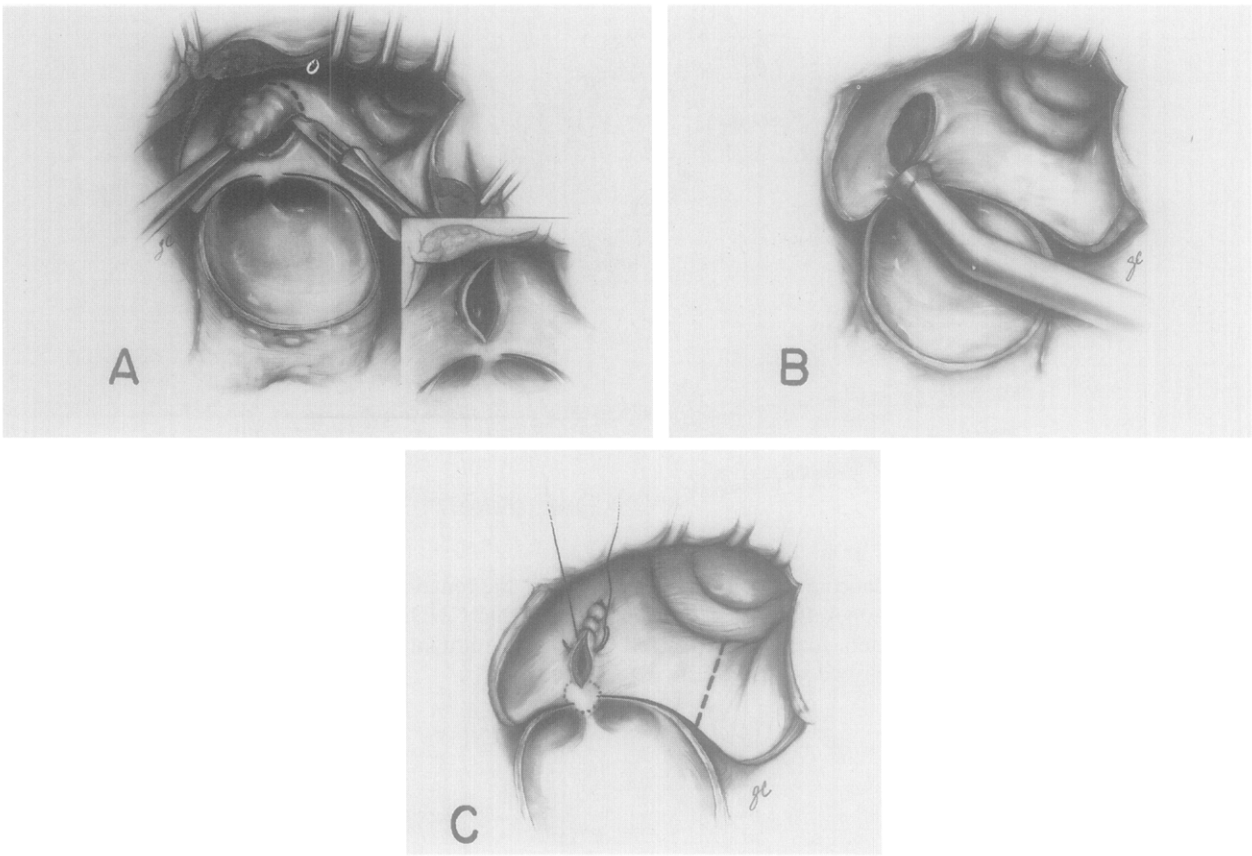

Fig. 6. A, The left atrial appendage is inverted and amputated at its base. The base of the appendage to the right, as viewed by the surgeon in this orientation, must be approached with special care because the circumflex coronary artery may course very near to this portion of the incision. Once the appendage is excised, a small bridge of tissue remains between the appendage amputation site and the two ends of the pulmonary vein encircling incision *(inset)*. This bridge of tissue can be divided and closed with sutures or it can be left intact and cryoablated. **B,** A 1.5 cm cryoprobe is applied to the bridge of tissue for 2 minutes at −60° C. The pulmonary vein isolation incision is much easier to close if this tissue bridge is left intact rather than surgically divided. **C,** After completion of the cryolesion *(dotted circle)*, the appendage amputation site is closed. The *dashed line* represents the site of the final incision, a posterior vertical left atriotomy that extends from the pulmonary vein isolation incision to the mitral valve anulus. (From Cox JL. The Maze III Procedure for Treatment of Atrial Fibrillation. In: Sabiston DC, ed. Atlas of Cardiothoracic Surgery. Philadelphia: WB Saunders, 1994:XIV-78. Modified and published with permission.)

the fat pad of the AV groove is exposed during completion of this portion of the T incision. To be absolutely certain that no atrial muscle fibers are left undivided by this incision, the surgeon must clean all such fibers, however small, off the fat pad using the knife or a nerve hook (Fig. 2, *C*). In addition, because the right atrium and right ventricle tend to fold over on one another at the level of the tricuspid valve anulus,[3] it is essential to apply a small cryolesion to the end of the T incision at the level of the valve anulus to be certain that no fibers remain at that level that are capable of conducting electrical impulses across the incision (Fig. 2, *D*). We apply a 3 mm cryoprobe (Frigitronics, Inc., Coopersurgical, Shelton, Conn.) to the site for 2 minutes at a temperature of −60° C. The lower end of this T incision is then closed up to the level of the top of the AV groove (Fig. 2, *E*). The remainder of this incision is left open, however, to improve the operative exposure for the rest of the surgical procedure.

Next, the anterior right atriotomy is performed beginning at the anteromedial base of the excised right atrial appendage (*dashed line* in Fig. 3, *A*). Once this incision is started, exposure is enhanced

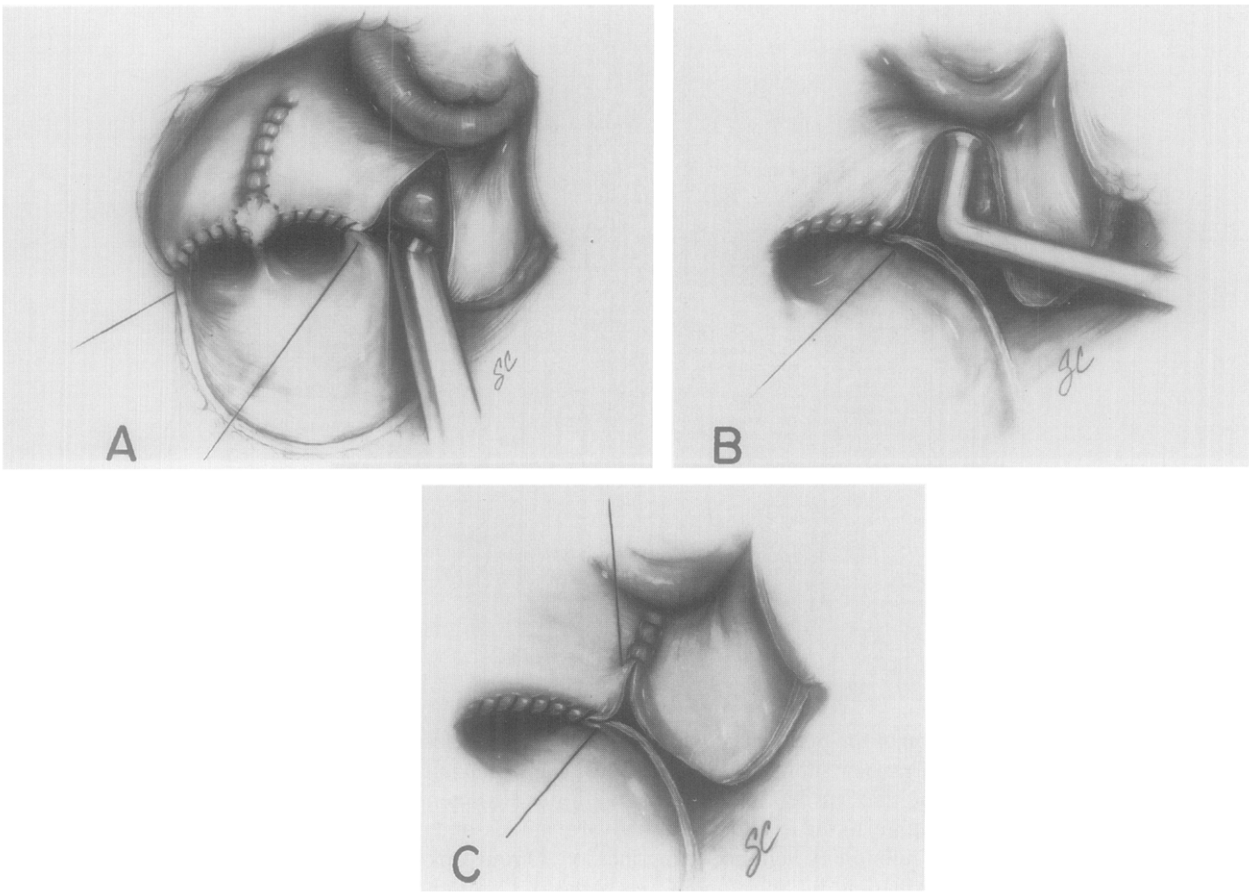

Fig. 7. A, Once the posterior vertical incision is made and all visible atrial myocardial fibers spanning the fat pad of the underlying AV groove have been divided, the coronary sinus is subjected to transmural cryothermia at −60° C for 3 minutes. Care is taken to avoid applying cryosurgery to the circumflex coronary artery. In addition, if retrograde cardioplegia is used, the cannula should be removed during this portion of the procedure. **B,** A 3 mm cryolesion is placed at the lower end of the incision adjacent to the mitral valve anulus. **C,** The posterior vertical left atriotomy is then closed. (From Cox JL. The Maze III Procedure for Treatment of Atrial Fibrillation. In: Sabiston DC, ed. Atlas of Cardiothoracic Surgery. Philadelphia: WB Saunders, 1994:XIV-78. Modified and published with permission.)

by again retracting the free wall of the right atrium superiorly and anteriorly (Fig. 3, *B*). This maneuver provides excellent exposure of the endocardial surface of the anteromedial right atrium, most of which is covered externally by the AV groove fat pad. The anteromedial right atriotomy is then completed to the level of the tricuspid valve (*dashed line* in Fig. 3, *B*). Again, it is essential to clean all atrial myocardial fibers, however small, off the fat pad by means of the knife or a nerve hook, after which a 3 mm cryolesion is placed at the level of the tricuspid anulus for the reasons defined earlier (Fig. 3, *C*). This entire anteromedial right atriotomy is then closed from the tricuspid valve up to the base of the excised atrial appendage (Fig. 3, *D*). This completes all of the right atriotomies, some of which are left open (Fig. 4) to facilitate optimal surgical exposure of the left side of the heart.

Left atrial and atrial septal incisions. The left atrium is opened initially via a standard atriotomy in the interatrial groove, much as one would do for a mitral valve procedure (Fig. 5, *A*). Once this standard left atriotomy has been performed, the septum is opened to optimize surgical exposure (*dashed line* in Fig. 5, *A*). This atrial septotomy is begun in the posterosuperior atrial septum approximately 2 to 3 cm below the orifice of the SVC. It is extended directly across the thick anterior limbus of the fossa ovalis and then across the thin fossa ovalis itself in the direction of the os of the coronary sinus. The

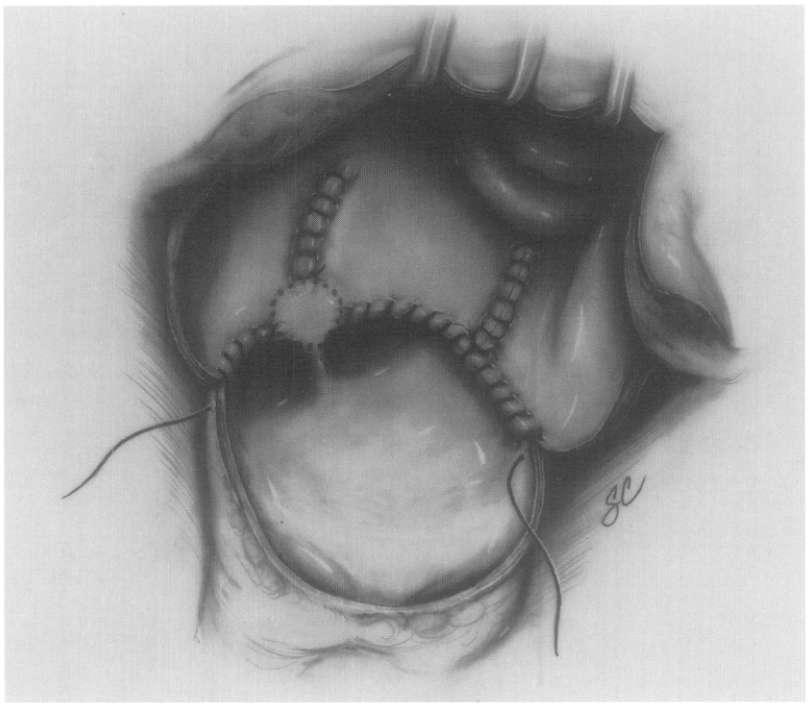

Fig. 8. The lower portion of the pulmonary vein isolation incision is closed across the posteroinferior free wall of the left atrium. This view shows the closed left atrial appendage excision site, the cryolesion on the bridge of left atrial tissue that was left intact to assure proper alignment and to expedite the closure, the posteroinferior left atriotomy to the level of the mitral valve anulus, and partial closure of the superior and inferior portions of the pulmonary vein encircling incision. (From Cox JL. The Maze III Procedure for Treatment of Atrial Fibrillation. In: Sabiston DC, ed. Atlas of Cardiothoracic Surgery. Philadelphia: WB Saunders, 1994:XIV-78. Published with permission.)

incision is terminated at the bottom of the fossa ovalis.

A valve retractor is then placed across the atrial septum into the left atrium and the superior and inferior ends of the standard left atriotomy are extended well onto the posterior free wall of the left atrium (Fig. 5, *B*). When the lower end of this incision is being extended care must be taken to stay well above the level of the left posterior AV groove to avoid injury of the circumflex coronary artery and the coronary sinus. This extension of both ends of the standard left atriotomy actually evolves into what we call the *pulmonary vein encircling incision* (*dashed lines*, Fig. 5, *B*). However, rather than completing the encirclement surgically, we now leave a small bridge of tissue between the two ends of the incision because of the technical difficulty of reattaching the completely severed pulmonary veins. In addition, after inverting the left atrial appendage and amputating it (Fig. 6, *A*), we actually leave a small confluence of intact atrial tissue between the two ends of the pulmonary vein encircling incision and the base of the excised atrial appendage (*inset*, Fig. 6, *A*). This intact atrial confluence is then cryoablated with a 1.5 cm cryoprobe at −60° C for 2 minutes (Fig. 6, *B*), which completely isolates the pulmonary veins and also functionally "connects" the encircling incision to the appendage incision to prevent reentry around the base of the excised atrial appendage. The base of the excised atrial appendage is then closed (Fig. 6, *C*) followed by partial closure of the two ends of the pulmonary vein encircling incision (Fig. 7, *A*).

The only remaining incision is the posteroinferior vertical left atriotomy that extends from the lower rim of the pulmonary vein encircling incision to the mid-posterior mitral valve anulus (Fig. 7, *A*, and *dashed line*, Fig. 6, *C*). This incision is transmural and a knife or small nerve hook is used to be certain that all myocardial fibers traversing this incision have been divided. The coronary sinus is exposed in the fat pad underlying the incision and its anterior

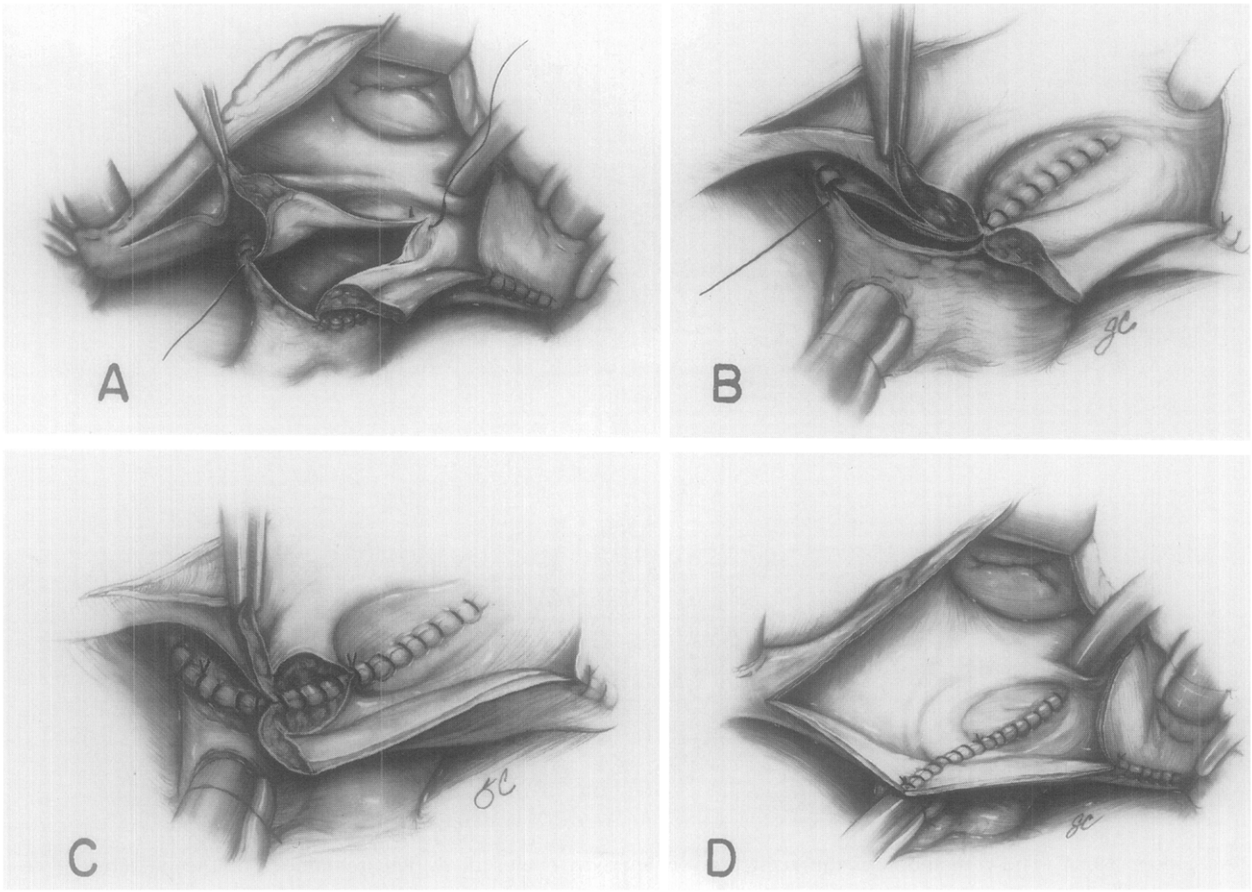

Fig. 9. A, Once the lower portion of the pulmonary vein isolation incision has been closed to the level of the atrial septum, the incision again resembles a more standard left atriotomy in the interatrial groove. At this point, the septal incision is closed, beginning at its lower end. A retrograde cardioplegia cannula is shown in the os of the coronary sinus. **B,** The thin portion of the fossa ovalis is closed up to the inferior margin of the anterior limbus. **C,** The left atrial side of the limbus of the fossa ovalis is closed in continuity with the remainder of the superior left atriotomy. **D,** The right side of the limbus of the fossa ovalis is closed in continuity with that portion of the posterior right atrial free wall that is medial to the posterior longitudinal right atriotomy. (From Cox JL. The Maze III Procedure for Treatment of Atrial Fibrillation. In: Sabiston DC, ed. Atlas of Cardiothoracic Surgery. Philadelphia: WB Saunders, 1994:XIV-78. Modified and published with permission.)

surface is cleaned of connective tissue. We no longer encircle the coronary sinus completely because we now have a right-angled cryoprobe that can be placed *posterior* to the coronary sinus, that is, on its epicardial surface (Fig. 7, *A*). Stretching the coronary sinus over the end of this 1.5 cm cryoprobe allows transmural (i.e., circumferential) cryoablation of the coronary sinus to be verified by direct visualization. We apply the cryothermia to the coronary sinus for 3 minutes at −60° C. Finally, to ensure that no conduction can occur across this incision near the mitral valve anulus, we place a 3 mm cryolesion (−60° C for 2 minutes) at that end of the incision (Fig. 7, *B*). The posteroinferior vertical left atriotomy is then closed from the mitral valve anulus up to the level of the pulmonary vein encircling incision (Fig. 7, *C*). During closure, we frequently mark this incision with metal clips so that if conduction across this portion of the left atrium should resume in the future, an event that usually results in refractory atrial flutter, the exact site of the incision can be identified fluoroscopically.

If the maze III operation is to be combined with elective repair or replacement of the mitral valve, it is at this point in the procedure, that is, after closure of the posteroinferior vertical left atriotomy, that

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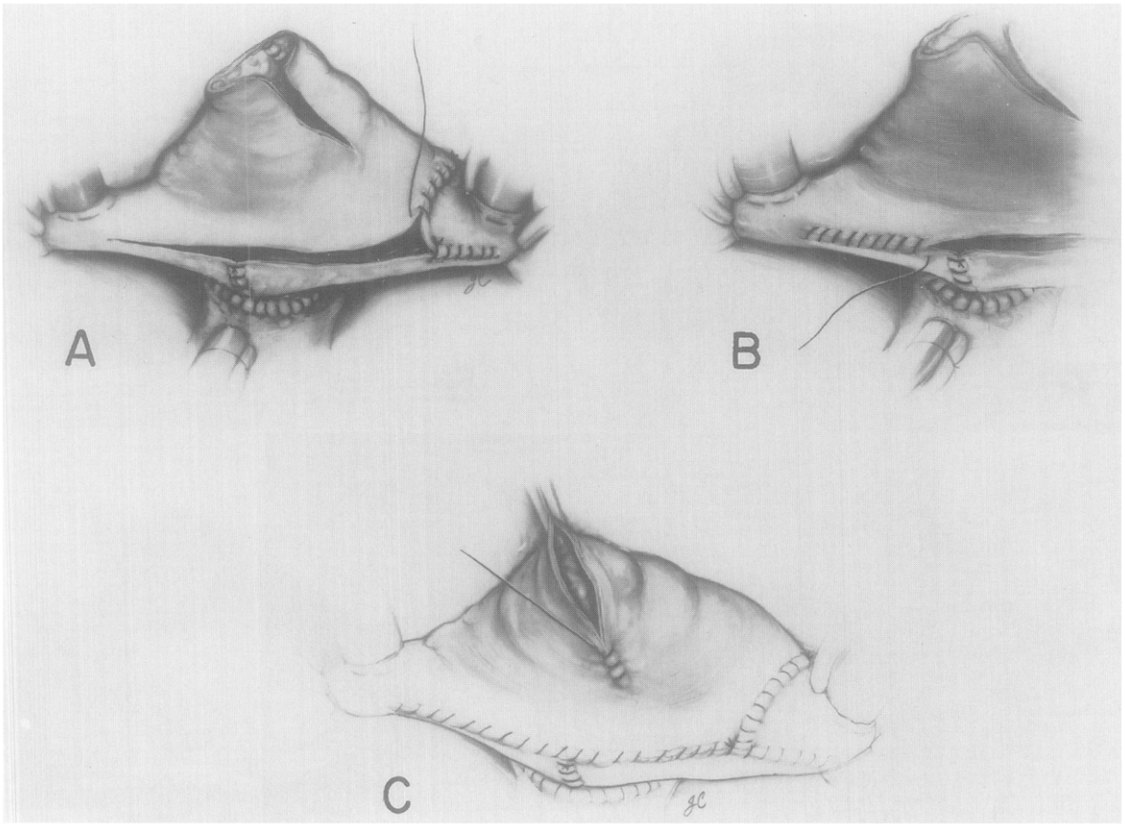

Fig. 10. A, The remainder of the right atrial T incision is closed. **B,** The remainder of the posterior longitudinal right atriotomy is closed. **C,** The lateral right atriotomy and the site of the amputated right atrial appendage are closed in continuity from a lateral to a medial direction. (From Cox JL. The Maze III Procedure for Treatment of Atrial Fibrillation. In: Sabiston DC, ed. Atlas of Cardiothoracic Surgery. Philadelphia: WB Saunders, 1994:XIV-78. Modified and published with permission.)

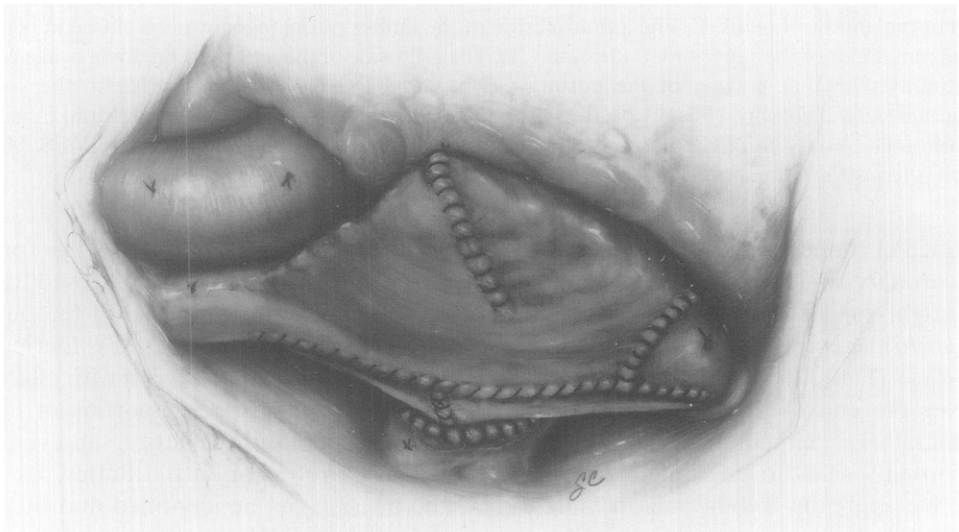

Fig. 11. The completed maze III procedure. (From Cox JL. The Maze III Procedure for Treatment of Atrial Fibrillation. In: Sabiston DC, ed. Atlas of Cardiothoracic Surgery. Philadelphia: WB Saunders, 1994:XIV-78. Published with permission.)

the mitral valve operation should be performed. This precludes the likelihood of the valve repair or replacement interferring with proper performance of the posterior vertical incision.

After closure of the posteroinferior vertical left atriotomy, the superior and inferior ends of the pulmonary vein encircling incision are closed (Fig. 8). It is usually easier to close the inferior portion over to the level of the atrial septum before closing the superior portion. This inferior suture line should be stopped at the top of the fossa ovalis (Fig. 9, *A B*). In addition, we now insert a left ventricular vent at this point through a separate suture in the right superior pulmonary vein.

Before complete closure of the superior portion of the pulmonary vein encircling incision, the atrial septum is closed. We prefer to close the septum beginning at the bottom of the fossa ovalis (Fig. 9, *A*). Once the fossa is closed, the septal suture is tied down to the inferior suture line coming from the inferior left atriotomy (Fig. 9, *B*). This leaves only a single straight incision to be closed that consists of the posterior (left-sided) layer of the limbus and the remaining portion of the superior left atriotomy (Fig. 9, *C*). Once this final opening in the left atrium is closed, the aortic crossclamp can be released.

Closure of remaining right atrial incisions. The anterior (right-sided) layer of the limbus is then closed in continuity with the short flap of posterior right atrial free wall attached to the septum (Fig. 9, *C* and *D*). Next, the remaining portion of the lower right atrial T incision is closed (Fig. 10, *A*), followed by closure of the posterior longitudinal right atriotomy extending from the SVC to the IVC (Fig. 10, *B*). Finally, the lateral right atriotomy is closed in continuity with the base of the excised right atrial appendage (Fig. 10, *C*). This maneuver completes the maze III procedure (Fig. 11).

A final word regarding suture material and technique seems in order. We use 3-0 and 4-0 monofilament suture exclusively, generally preferring 4-0 for the right atrium and 3-0 for the left atrium. However, the posteroinferior vertical left atriotomy is closed with 4-0 suture (Fig. 7, *C*) because of the delicacy of the atrial tissue in that region. All suture lines are placed in a simple continuous single-layer fashion. It is important, however, to ligate intramyocardial arterial bleeders with a separate transfixion suture to prevent postoperative bleeding that may not be controlled by the simple running suture used to close the atriotomies.

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